LA-UR-19-30127

Title:	Evaluation of FTWC Vent System
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Intended for:	Report
	Environmental Regulatory Document
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LA-UR-19-30127

Evaluation of FTWC Vent System

Revision 2, July 2020

This document was issued originally in October 2019, to record the series of tests that were performed by EPC-CP to commission the venting system for the Flanged Tritium Waste Containers (FTWCs).

As part of the Management Self-Assessment (MSA) in February 2020, prior to FTWC venting operations, it was requested to have this LA-UR reviewed for accuracy. Murray Moore, Ph.D., PE, an engineer in charge of the RP-SVS Aerosol Engineering Laboratory, reviewed the document to ensure all EPA compliance criteria were met for the stack sample system commissioning test. Dr. Moore's evaluation appears at the end of this document. More information appears on page r1-1.

Later in the MSA, in July 2020, a second revision was requested to document the software quality assurance information for the calculations performed in this set of analyses.

The analyses in this document were performed using Microsoft Excel 2016. A database developed in Microsoft Access 2016, dubbed "STACKS," is not directly used in this report but output from this database is referenced. Therefore, the information on Microsoft Excel 2016 and Microsoft Access 2016 along with the computer hardware appears below, and the Form 2033 assessment for the STACKS database (4 pages) follows on the next four pages. After this information, the header page for the Revision 1 will appear, then the original LA-UR document.

D. Fuehne & R. Lattin, 27 July 2020

COMPUTER HARDWARE AND SOFTWARE UTILIZED IN LA-UR-19-30127

Software: Microsoft Office Professional Plus 2016
Microsoft Excel 2016 (16.0.4954.1000) MSO (16.0.4939.1000) 32-bit (D. Fuehne)
Microsoft Access 2016 (16.0.4924.1000) MSO (16.0.4939.1000) 32-bit (D. Fuehne)

Microsoft Access 2016 (16.0.4993.1001) MSO (16.0.5032.1000) 32-bit (R. Lattin)
Microsoft Excel 2016 (16.0.5026.1000) MSO (16.0.5032.1000) 32-bit (R. Lattin)

Hardware: Utilized on desktop workstation
Hewlett-Packard, HP EliteDesk 800 (D. Fuehne)
        Processor: Intel Core i5-6500 CPU @ 3.20GHz 3.19; 16 GB RAM
        Running Windows 10 Enterprise; version 1909; OS Build 18363.592
Hewlett-Packard, HP Z440 (R. Lattin)
        Processor: Intel Xeon CPU E5-1620 v4 @ 3.50GHz 3.50 GHz; 16.0 GB RAM
        Running Windows 10 Enterprise; version 1909; OS Build 18363.959

The Software Owner RLM must retain completed forms as a record.

Safety/Non-Safety Software Determination, Categorization, and Software Risk Level (SRL)

(See Page 5 for Guidance)

Part 1: Document the rationale supporting the reasonable probability that the software may be safety software, or risk significant software.

1.1 Excluding personal productivity software that does not provide calculation output (e.g., e-mail software, presentation software), indicate whether the software is or will be used in connection with the design, analysis and/or operation of:

- ☐ a nuclear (including radiological) facility (Ref. LANL Nuclear Facility List, Conduct of Operations Resources Website), or

- ☐ an accelerator, live-firing range, biological hazard facility, high explosive facility, or moderate- or high- chemical hazard facility as determined using SBP111-1, *Facility Hazard Categorization and Documentation*; or

- ☐ LANL's Essential Functions as described in SEO-COOP-006, *LANL NA-LA Continuity of Operations (COOP) Plan.*

Provide supporting comments (as necessary to document the selection above).

The software items and activities described below are not managed or performed within the operating scope of any single LANL Nuclear Facility (including radiological), accelerator, live-fire range, biological hazard facility, high explosives facility, or moderate- or high-chemical hazard facility. The software items and activities are used to support environmental compliance elements of Safety Management Programs across the entire laboratory. As such, multiple LANL facility Safety Basis documents make general references to activities related to the use of these software items; however, they do not credit them with any hazard control function pertaining to the design, analysis, and/or operations of any facility.

Part 2: Document the software information, software application(s) and software function(s). A separate form may be used for each software item or one form may be used for multiple software items.

2.1 Provide software name(s). STACKS	2.2 Provide software version(s). Microsoft Access 16.0	2.3 Indicate software owner (SO). RAEM Data Manager	2.4 Indicate SO organization. EPC-CP

2.5 Provide a description of the specific facility application(s) to sufficient detail to allow the software to be readily traceable to the point(s) of application within the facility. Include technical area (TA) and building number; or, site-wide or Facility Operating Directorate (FOD)-wide use. Add other descriptive information as required.

STACKS is a database and analysis code used for evaluating and storing stack flow data. It is code that was developed at LANL by Libby Jones, and it is controlled/maintained by the RAEM Data Manager. It is used to support the planning and performance monitoring/analysis of various Laboratory activities to ensure compliance with the National Emissions Standards for Emissions of Radionuclides other than Radon from Department of Energy Facilities (Rad-NESHAP) as promulgated in 40 CFR 61, Subpart H. The software is available for use on the institutional LANL server (dcstorage) with the RAEM files. Output files include electronic files (posted and maintained on the institutional LANL server [dcstorage] with the RAEM files) and hard-copy printouts (stored in the EPC White Rock records center).

2.6 Indicate System, Structure or Components (SSCs) controlled or affected by the software. Indicate NA if not applicable.

2.6.1 Provide SSC name(s).

NA

2.6.2 Provide functional requirement(s) of the software associated with the SSC.

NA

2.6.3 Provide reference document(s) describing the SSC/software.

NA

Provide supporting comments (as required).

2.7 Indicate facility classification (SBP111-1), design, or analysis controlled or affected by the software. Indicate NA if not applicable.

NA

2.7.1 Provide facility classification, design or analysis name.

NA

2.7.2 Provide software functional requirement(s) associated with the facility classification, design or analysis.

NA

2.7.3 Provide reference document(s) describing the facility classification, design, or analysis.

NA

Provide supporting comments (as required).

2.8   Indicate the hazard control, Safety Management Program (SMP) and or technical safety requirements (TSRs) controlled or affected by the software. Indicate NA if not applicable.

2.8.1 Provide the hazard control, SMP and/or TSR name.

 Radiation Protection SMP and Hazardous Material Protection SMP.

2.8.2 Provide the software functional requirement(s) for the hazard control, SMP and/or TSR.

 None

2.8.3 Provide reference document(s) describing the hazard control, SMP and/or TSR.

 Multiple LANL facility Documented Safety Analyses (DSAs) and LANSCE Safety Assessment Document (SAD).

 Activities related to environmental air monitoring (monitoring, sampling, analysis and reporting) are not provided in a standardized location within each document but are typically generally described within the Chapters 7 (Radiation Protection SMP, Section 7.7 Radiological Monitoring) and 8 (Hazardous Material Protection SMP, Section 8.7 Hazardous Material Monitoring).

Provide supporting comments (as required).

 Rad-NESHAPS work activities support Laboratory compliance with the 10-mrem/year standard (potential dose to Maximally Exposed Off-site Individual [MEOI]) required by 40 CFR 61, Subpart H. This standard is far below Evaluation Guide (EG) threshold values used to determine the applicability of Safety-Level controls in LANL facility Safety Basis documents (e.g. DSAs, SAD, BIOs, etc.). As such, software used to support these activities, such as STACKS, are not credited with any explicit hazard control function as defined in any LANL facility Safety Basis document. Descriptions of the associated activities and equipment provided (or referenced) in the SMP chapters are intended to describe a Defense-in-Depth strategy, where non-safety programs (including associated processes, procedures, activities, and/or equipment) provide additional, redundant layers of protection against hazards by ensuring that facilities are operated in a safe manner that adequately protects workers, the public, and the environment.

Part 3: Determine whether the software type is (1) safety software; or (2) non-safety software and the associated category for each type.

3.1 Check **one** of the following (3.1.1 through 3.1.5) to determine one of the two software types (safety software or non-safety software) and one of the associated 5 categories for each type (i.e. Categories include SSS, SHADS or SMACS for safety software; and, Risk Significant or Commercially Controlled for non-safety software).

Note: If software is determined to be safety software or risk significant software, complete all parts of this form. If software is determined to be commercially controlled software, complete all parts of this form **except for Part 4**.

3.1.1 Safety software: SSS ☐	This is software for a nuclear (including radiological) facility that performs, or will perform a safety function as part of a Structure, System, and Component (SSC) and is cited in either (a) a Department of Energy (DOE)-approved documented safety analysis; or, (b) an approved hazard analysis per DOE P 450.4A, *Integrated Safety Management Policy* and 48 Code of Federal Regulations (CFR) 970-5223-1, *Integration of Environment, Safety, and Health into Work Planning and Execution.* This is safety software and is categorized as Safety System Software (SSS). Provide supporting comments (as required). This software is not part of any SSC credited in LANSCE SAD or LANL facility DSAs (or other Safety Basis facility documents), nor is it part of an SSC credited in any DOE P450.4A and 48 CFR 970.5223-1 hazard analyses.
3.1.2 Safety software: SHADS ☐	This is software that is used, or will be used to classify, design, or analyze nuclear (including radiological) facilities. This software is not part of an SSC, but helps to ensure the proper accident or hazards analysis of nuclear (including radiological) facilities or an SSC that performs a safety function. This is safety software and is categorized as Safety and Hazard Analysis Software and Design Software (SHADS). Provide supporting comments (as required). This is an analysis software used to support analysis activities specific to EPA compliance; however, it is not used to support (design and/or analyze) any SSCs credited with a safety function and is not used to develop hazard or accident analysis scenarios as documented in various LANL facility Safety Basis documents.
3.1.3 Safety software: SMACS ☐	☐ This is software that performs or will perform a hazard control function in support of nuclear (including radiological) facility radiological safety management programs (SMPs) or technical safety requirements (TSRs). This is safety software and is categorized as Safety Management and Administrative Controls Software (SMACS). Provide supporting comments (as required). This software is not credited with any hazard control function described in an SMP or documented in a TSR.

	☐	This is software that performs, or will perform a control function in support of a nuclear (including radiological) facility necessary to provide adequate protection from nuclear (including radiological) facility radiological hazards. It supports eliminating, limiting, or mitigating nuclear hazards to workers, the public, or the environment as addressed in 10 CFR 830, *Nuclear Safety Management*, 10 CFR 835, *Occupational Radiation Protection*, and the Department of Energy Acquisition Regulation (DEAR) Integrated Safety Management System (ISMS) clause 48 CFR 970.5223-1, *Integration of Environment, Safety, and Health into Work Planning and Execution*. This is safety software and is categorized as Safety Management and Administrative Controls Software (SMACS). Provide supporting comments (as required). Although the DEAR ISMS clause 48 CFR 970-5223-1 does consider pollution prevention as part of Safety, it does not provide a threshold value for allowable MEOI or environmental exposures. The other referenced sources (10 CFR 830 and 10 CFR 835) do provide or reference explicit threshold values, and the use of STACKS in support of Rad-NESHAP activities operates well below those values (i.e. does not raise to the level requiring Safety-Level hazard control). As such, use of this software by the RAEM team is not considered SMACs.
3.1.4 Non-safety software: Risk Significant ☐		This is software that is, or will be used for any of the purposes that safety software is used for only such purposes are in or for an accelerator, live-firing range, biological hazard facility, high explosive facility, or moderate- or high- chemical hazard facility OR, failure of the software would <u>prevent</u> LANL from performing Essential Functions as described in SEO-COOP-006, *LANL NA-LA Continuity of Operations (COOP) Plan.* This is non-safety software and is categorized as Risk Significant software. Provide supporting comments (as required). This software is not used for any safety software purpose (as described in Sections. 3.1.1 thru 3.1.3 above) and would not prevent the performance of a LANL Essential Function.
3.1.5 Non-safety software: Commercially Controlled ☒		This is software that is not, or will not be used for any of the above purposes in 3.1.1–3.1.4. Such software may be acquired (including commercial off the shelf (COTS)) or designed software. Examples of this software include personal productivity software (e.g., Microsoft PowerPoint, Oracle Project Primavera, MS Outlook, etc.) and other types of software (e.g., some business accounting systems, facility personnel comfort temperature monitoring systems).This is non-safety software and is categorized as Commercially Controlled software. Proceed to **Part 5.** Part 4 is not required. Provide supporting comments (as required). As mentioned above in sections 2.8 and 3.1.3, STACKS is used in support of Rad-NESHAP activities, including stack monitoring. Those activities, although discussed in general terms in multiple LANL facility Safety Basis documents, are not directly credited with any hazard control function. As such, software used in support of the performance of those activities is consistent with non-safety software applications.

Part 4: Determine the Software Risk Level (SRL).
4.1 Complete this section for safety software and risk significant software only. Do not complete this section for commercially controlled software. Check **only one** of the following to determine the SRL. Text shown in *[brackets]* is applicable to safety software only.

SRL 1 ☐   4.1.1 This level includes software applications that meet one or more of the following criteria. Failure of the software could:
    ▪ *[Compromise a limiting condition for operation].*
    ▪ *[Cause a reduction in the safety margin for a safety SSC that is cited in a DOE approved documented safety analysis.]*
    ▪ Cause a reduction in the safety margin for other systems such as toxic or chemical protection systems that are cited in either (a) a DOE approved documented safety analysis or (b) an approved hazard analysis per DOE P 450.4A, *Integrated Safety Management Policy*, and the DEAR ISMS clause (48 CFR 970.5223-1, *Integration of Environment, Safety, and Health into Work Planning and Execution*).
    ▪ Result in non-conservative safety analysis, design, or misclassification of facilities or SSCs.
 	
Provide supporting comments (as required).

SRL 2 ☐	4.1.2	This level includes *[safety]* software applications that do not meet SRL 1 criteria, but meet one or more of the following criteria:
		▪ *[Safety management databases used to aid in decision making whose failure could impact safety SSC operation.]*
		▪ Software failure that could result in incorrect analysis, design, monitoring, alarming, or recording of hazardous exposures to workers or the public.
		▪ *[Software failure could compromise the defense-in-depth capability for a nuclear (including radiological) facility.]*
		Provide supporting comments (as required).
SRL 3 ☐	4.1.3	This level includes software applications that do not meet SRL 2 criteria, but meet one or more of the following criteria. Failure of the software could:
		▪ Cause a potential violation of regulatory permitting requirements.
		▪ Affect environment, safety, health monitoring, or alarming systems.
		▪ Affect the safe operation of an SSC.
		Provide supporting comments (as required).

Part 5: Attest to compliant completion, review and approve. <u>A signature is required in 5.1, 5.2 and 5.3 for all completed 2033 Forms.</u>

5.1 As the Software Owner (SO), I have determined the software type, category, and as appropriate, SRL, in accordance with <u>P1040</u>, *Software Quality Management* and the instructions associated with this form. Provide Name/Z No. (print) Rebecca Lattin 219035	Signature, Date REBECCA LATTIN (Affiliate) Digitally signed by REBECCA LATTIN (Affiliate) Date: 2020.04.06 14:30:41 -06'00'
5.2 As the Software Owner Responsible Line Manager (SO RLM or SRLM), I have reviewed and approve the determination of the software type, category and, as appropriate, SRL for the software as described on this form. Provide Name/Z No. (print) David Fuehne 115862	Signature, Date *David P Fuehne* Digitally signed by DAVID FUEHNE (Affiliate) Date: 2020.04.07 11:28:17 -06'00'
5.3 As the ☒ <u>Facility Design Authority Representative</u> (FDAR) for my representative facilities, as the ☐ LANL Design Authority (DA), or, as the ☐ Responsible Associate Laboratory Director (RALD), I have reviewed and approve the determination of the software type, category and, as appropriate, SRL for the software as described on this form. Check one. Provide Name/Z No. (print) Robert Swickley 228406 **Note:** The RALD is authorized to review and approve <u>Form 2033</u> (rather than the FDAR or DA) for software applications where, **as determined by the FDAR or DA**, the FDAR or DA does not have the knowledge and/or a reasonable connection to the software.	Signature, Date Robert Louis Swickley Digitally signed by Robert Louis Swickley Date: 2020.04.07 21:38:32 -06'00'

Supporting Comments Continuation Page

As needed, use this space to provide supporting comments. Provide the Form section number that corresponds to the comments.

LA-UR-19-30127

Evaluation of FTWC Vent System

Revision 1, March 2020

This document was issued originally in October 2019, to record the series of tests that were performed by EPC-CP to commission the venting system for the Flanged Tritium Waste Containers (FTWCs).

As part of the Management Self-Assessment in February 2020, prior to FTWC venting operations, it was requested to have this LA-UR reviewed for accuracy. Murray Moore, Ph.D., PE, an engineer in charge of the RP-SVS Aerosol Engineering Laboratory, reviewed the document to ensure all EPA compliance criteria were met for the stack sample system commissioning test. Dr. Moore's evaluation appears at the end of this document. This review is 30 pages, consisting of a short introduction & summary, a list of references, several red-lined pages from the original published LA-UR-19-30127, and several pages of calculations verifying data from the original LA-UR.

The original text of the LA-UR begins on the next page and is 32 pages, unchanged from the October 2019 version.

8 pages – original abstract and summary

5 pages – velocity profile analysis

3 pages – cyclonic flow analysis

9 pages – SF6 tracer gas raw data spreadsheets & analysis, Configuration 1 (small blower)

4 pages – SF6 tracer gas testing for Configuration 2 (large blower)

1 page – scale model applicability under ANSI N13.1

2 pages – Reynolds number calculations for Configuration 1 and Configuration 2

Note that Dr. Moore points out an error in calculating the Reynolds number; we used an approximation for air viscosity and air density in our 2019 calculations rather than determining exact atmospheric conditions. Our results were within 10% of those calculated by Dr. Moore. Since the Reynolds number test is a binary test (requiring the value to simply be greater than 10,000 in order to meet ANSI N13.1 criteria for scale model usage), and our values were more than an order of magnitude above this minimum threshold, the approximation we used was satisfactory for our purposes and the margin of error is not a factor.

D. Fuehne & R. Lattin, 19 March 2020

Abstract

A monitored exhaust system has been designed for use in venting the Flanged Tritium Waste Containers (FTWCs) at LANL. This system will provide controlled exhaust and emissions monitoring for the FTWCs, and also provide general area exhaust around the venting operations to measure any emissions which may bypass the primary vent system.   A full description of the process and need for the system is described in the Pre-Construction Application[1] for this project. This document describes the commissioning testing performed on the FTWC vent system to prepare it for use. The system has been tested and shown to meet ANSI standard requirements and is fully suitable for use.

A. Background

Airborne emissions of radioactive material from Department of Energy facilities are regulated by the Clean Air Act, in the Radionuclide NESHAP[2] or Rad-NESHAP.   Methods for measuring emissions are described in the Rad-NESHAP and also in the American National Standards Institute (ANSI) standard[3] N13.1, which has been incorporated by reference into the Rad-NESHAP. Under ANSI N13.1, four tests are performed to determine if the proposed sampling location is adequate for representative sampling of the emissions exhaust stream. These include: (1) a measurement of the velocity profile, (2) a measurement of the cyclonic flow angle, (3) a measurement of mixing of tracer gas, and (4) a measurement of mixing of large aerosol particles. The tests will show the stack either meets all the needed specifications or that it is not in compliance. Note that since the FTWC emissions only contain airborne tritium in gas or vapor form, the fourth test regarding aerosol particulate mixing is not needed.

The exhaust system was built by EPC-CP personnel using modular "Quick Flange" duct work, 10 inches in diameter. The system has a blower to supply air movement, a rigid section of duct approximately 12 feet long, and one or two flexible duct sections of up to 25 feet each. Another five foot section of rigid duct is connected to the blower's vertical exhaust to discharge air above the worker breathing zone. Measurements on the original system indicated that the first system, using a small ¾ horsepower blower, did not provide sufficient flow to safely vent the FTWCs during initial venting operations at TA-54. A larger blower (2 horsepower) was purchased that would fit the existing duct work and provide sufficient flow. Figure 1 shows a line schematic of the exhaust system.

The full suite of ANSI N13.1 testing was performed on the original system (dubbed "Profile 1"). Under ANSI N13.1 parameters, testing from one system can be applied to a second system if certain parameters are met; this is the "scale model criteria" described later in this document. If these criteria

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[1] LA-UR-18-26283 r2, "Application for Pre-Construction Approval under 40 CFR Subparts A and H for Venting of Flanged Tritium Waste Containers (FTWCs) at TA-54." May 16, 2019. This application was transmitted to EPA Region 6 via memo EPC-CP-19-137, "Transmittal of Application for Pre-Construction Approval and Notice of Intent to Start Operations under 40 CFR 61 Subparts A and H for Venting of Flanged Tritium Waste Containers (FTWCs) at TA-54," May 17, 2019.

[2] National Emissions Standards for Hazardous Air Pollutants – Radionuclides. Title 40, Code of Federal Regulations, Part 61, Subpart H, "National Emissions Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities." Referred to as the Rad-NESHAP. Compliance with this regulation at LANL is managed by the Environmental Protection and Compliance Division – Compliance Programs Group, EPC-CP.

[3] ANSI/HPS N13.1-1999, "Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities." Issued 1999, reaffirmed without changes in 2011.

are met, the system with the larger blower (dubbed "Profile 2") is considered to have met the same test results as the original tested model system.
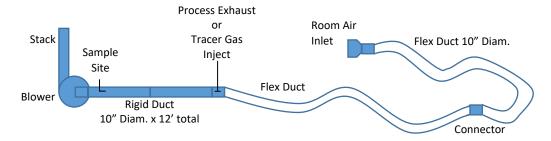

Figure 1: Line Schematic of FTWC Vent System

Test results from the Profile 1 system are included in Section B. Scale model criteria from ANSI N13.1 and the evaluation of acceptability for using Profile 1 test data as a model for Profile 2 operations appears in Section C.

Note that there are different flow configurations for each flow profile. Configuration 1 is the rigid duct only; Configuration 2 is the rigid duct with one section (25 feet) of flex ducting attached; and Configuration 3 is the rigid duct with two sections (50 feet) of flex ducting attached. We only anticipate using the FTWC vent system in either Configuration 2 or 3 during actual operations.

For the ANSI N13.1 testing, we only did the tracer gas testing in Configuration 2. Because the tracer injection location is at the rigid duct section inlet, the number of flexible duct sections upstream of the injection point will not affect test results. Configuration 2 was deemed to be conservative and bounding for both Configuration 2 and 3.

B. Flow Rate & ANSI N13.1 Test Results

Flow measurements for Profile 1 (small blower) and Profile 2 (larger blower) appear in Table 1 for measured configurations.

Table 1: Measured Air Velocity & Flow Rates for FTWC Vent System			
Flow Profile (blower size)	Config 1 – Rigid Duct Only	Config 2 – Rigid + 25' Flex	Config 3 – Rigid + 50' Flex
Profile 1 (3/4 HP Blower)	3322 ft/min velocity 1812 actual cfm flow	2115 ft/min velocity 1154 actual cfm flow	1440 ft/min velocity 785 actual cfm flow
Profile 2 (2 HP blower)	N/A Not Tested	3511 ft/min velocity 1915 actual cfm flow	2802 ft/min velocity 1528 actual cfm flow

The system was also tested for compliance with location requirements in ANSI N13.1. Test results for Profile 1 of the FTWC venting system appear below in Table 2. Explanatory notes appear later in the

document and in the attached data sheets. Note that for tests below, the coefficient of variation (COV) is defined as the standard deviation of the measurements divided by the average of the measurements.

Table 2: Test Result Summary of ANSI N13.1 Sampling Location Requirements for FTWC Venting, Profile 1			
Test	**Criteria**	**Pass/ Fail**	**Test Data**
Uniform Velocity Distribution	Coefficient of variation over the central 2/3 area of the cross section must be less than 20%	Pass	Config 1: 3.45% Config 2: 3.91% Config 3: 2.40%
Absence of Cyclonic Flow	Flow angle <20° relative to the long axis of the stack and nozzle inlet	Pass	Config 1: 4.1° Config 2: 8.3° (Prof.2) Config 3: 5.8°
Tracer Gas Well Mixed	Tracer gas concentration over the central 2/3 area of the cross section has a coefficient of variation within 20%. Five injection points tested.	Pass	North Inject: 4.1% South Inject: 10.9% Center Inject: 3.1% Bottom Inject: 2.9% Top Inject: 13.6%
Tracer Gas Well Mixed	The maximum value of tracer gas concentration shall not be more than 130% of the mean value at any point on a complete Method 1 set of velocity traverse points; minimum value > 70% mean.	Pass	North: 106%; 92% South: 118%; 83% Center: 109%; 94% Bottom: 109%; 96% Top: 128%; 74%
Aerosol Well Mixed	Aerosol gas over the central 2/3 area of the cross section has a coefficient of variation within 20%	Pass	N/A Aerosol test not needed if particulate pollution not present

These test results show that Profile 1 meets ANSI N13.1 criteria for sample siting. Under this ANSI standard, these data can be used as a scale model for similar systems. In this case, Profile 1 is used as a scale model for Profile 2 operations. Section C shows the criteria that must be met for scale model applicability.

C. Scale Model Applicability

In order for a tested system to be used as a scale model for new systems (dubbed the "candidate system"), certain criteria must be met under ANSI N13.1. These criteria are described in Table 3, along with the applicability to the FTWC ventilation systems (Profile 1 and Profile 2). Note the criteria numbers are from ANSI N13.1; criterion 2 in the standard has three separate components that are split out in Table 3.

Table 3: Conditions for stack to be a Scale Model for future designs (ANSI N13.1, section 5.2.2.2)			
Criteria	Description	FTWC Vent System Applicability	
1. Geometrically Similar	The two systems have proportional critical dimensions; and the sampling location on tested stack meets the N13.1 criteria.	Geometrically identical systems; OK	
2.1 Flow Scaling Factor: Product of Velocity and hydraulic diameter	The product of the mean velocity and the hydraulic diameter must within a factor of 6	Identical diameters; therefore, ratio of velocities between candidate system and tested system must be less than 6. Configuration 2: 3511/2115 = 1.66; OK Configuration 3: 2802/1440 = 1.95; OK	
2.2 Hydraulic diameter	Hydraulic diameter of both systems at least 250 millimeters (note: hydraulic diameter of round duct is same as the duct's inner diameter).	Identical diameter for both systems; 10 inches = 254 mm; OK	
2.3 Reynolds Number	The tested stack and candidate stack both exhibit turbulent flow; both must have a Reynolds number over 10,000. (1E4)	Profile 1 (tested) Config 2 = 1.57E5; OK Config 3 = 1.07E5; OK	Profile 2 (candidate) Config 2 = 2.60E5; OK Config 3 = 2.07E5; OK
3. Candidate stack meets velocity profile COV requirements	The velocity profile of the candidate system has a COV of less than 20% over the center 2/3 area of the duct.	Profile 2 (candidate system) COV: Config 2: 6.81%; <20%; within range above; Config 3: 4.78%; <20%; within range above Both configurations OK	
4. Similar Velocity COV for each system	The candidate stack must have a velocity COV within five percentage points of the tested system's velocity COV.	Minimum COV: Config 2: 0% Config 3: 0%	Maximum COV: Config 2: 8.91% Config 3: 7.40%
5. Similar Sampling Location	The sampling location in the candidate system must be geometrically similar to that of the tested system, and in the center 1/3 of the duct.	Identical system; sample line in center of duct; OK	

D. FTWC Vent System Testing Details

More detailed descriptions of the criteria from ANSI N13.1 and results of testing appear here. Calculation sheets will follow in the published version. Calculation worksheet files are called out after each summary table. Raw field measurement forms are maintained in the EPC-CP records system.

Uniform Velocity Distribution: (PASS, all configurations)

Criteria:
1. Coefficient of variation over the central 2/3 area of the cross section must be less than 20%

Results:
The sampling location stack velocities were measured using a pitot tube and an electronic digital manometer on 8/14/2019 for Profile 1. Profile 2 data was measured 9/27/2019.

Table 4: Velocity Profile Test Details				
Profile & Configuration	Description	Avg Velocity (fpm), Center 2/3 Duct	Velocity Std. Dev., Center 2/3 Duct	COV
Profile 1, Config 1	Small blower; Rigid duct only	3395	117	3.45%
Profile 1, Config 2	Small blower; Rigid duct + 25' Flex	2164	85	3.91%
Profile 1, Config 3	Small blower; Rigid duct + 50' Flex	1458	35	2.40%
Profile 2, Config 2	Large blower; Rigid duct + 25' Flex	3575	244	6.81%
Profile 2, Config 3	Large blower; Rigid duct + 50' Flex	2850	136	4.78%
	Calculation workbook: worksheets:	FTWC STACK DATA_VelocityProfile.xlsx sheet: Config 1 – Rigid Duct Only sheet: Config 2 – 25ft Flex sheet: Config 3 – 50ft Flex sheet: Profile 2		

Absence of Cyclonic Flow: (PASS)
Criteria:
1. Flow angle <20° relative to the long axis of the stack and nozzle inlet

Results:
Cyclonic measurements were taken on 8/19/2019 for Profile 1, Configurations 1 and 3. We determined that if these met flow angle criteria, Configuration 2 would also meet the criteria. On 10/2/2019, Configuration 2 was measured using Profile 2 (large blower) for completeness. The above requirement was met for all configurations, as shown in Table 5.

Table 5: Cyclonic Flow Test Details		
Profile & Configuration	**Description**	**COV**
Profile 1, Config 1	Small blower; Rigid duct only	4.12%
Profile 2, Config 2	Large blower; Rigid duct + 25' Flex	8.31%
Profile 1, Config 3	Small blower; Rigid duct + 50' Flex	5.75%
Calculation workbook: worksheets:	FTWC STACK DATA_Cyclonics.xlsx sheet: Config 1 sheet: Config 2 sheet: Config 3	

Tracer Gas Well Mixed: (PASS)

For the tracer gas mix testing, a sulfur hexafluoride gas bottle with a bent tube injection probe was used to inject the SF6 gas into FTWC exhaust duct near the inlet of the rigid duct. A portable detector was used at the sampling plane to measure the gas concentration along a 2 by 8 traverse. Per the ANSI N13.1 standard, five injection points were tested; the centerline, the duct top, duct bottom, north wall at centerline, and south wall at centerline. We used two detectors in parallel for this test, but only reporting here data from the detector dubbed "Instrument 92" as that instrument has proven more stable over past years.

Data in the Table 6a and 6b below represent average values at each traverse point using the instruments' "log" feature which records concentrations every five seconds. Concentrations were measured at each traverse point for one minute; data Aug 23 showed that the instrument would stabilize after about 30 seconds. Therefore, we used the last 4 readings of each minute's log to determine the average concentration at each traverse point.

     Criteria:
1. Coefficient of variation over the central 2/3 area of the cross section within 20%.
2. The maximum value of tracer gas concentration shall not exceed the mean value by more than 30% of the mean value at any point on a complete Method 1 set of velocity traverse points.

Table 6a: Tracer Gas Mixing Test Details – Coefficient of Variation, Center 2/3 Duct Area				
Profile & Configuration	Injection Point	Avg SF6 Conc.	Std Dev SF6 Conc	COV
Profile 1, Config 2	North Wall	3.499 ppm	0.145 ppm	4.1%
Profile 1, Config 1	South Wall	3.225 ppm	0.351 ppm	10.9%
Profile 1, Config 1	Center Line	3.262 ppm	0.102 ppm	3.1%
Profile 1, Config 1	Bottom Wall	3.737 ppm	0.110 ppm	2.9%
Profile 1, Config 1	Top Wall	3.578 ppm	0.488 ppm	13.6%
FTWC STACK DATA_SF6_Testing.xlsx; worksheet Aug23_InfraRan_Calcs				

Table 6b: Tracer Gas Mixing Test Details – Maximum Deviation, Full Plane Area				
Profile & Configuration	Injection Point	Mean SF6 conc., ppm	Max ppm; %	Min ppm; %
Profile 1, Config 2	North Wall	3.500 ppm	3.715; 106%	3.215; 92%
Profile 1, Config 1	South Wall	3.195 ppm	3.775; 118%	2.653; 83%
Profile 1, Config 1	Center Line	3.306 ppm	3.595; 109%	3.113; 94%
Profile 1, Config 1	Bottom Wall	3.763 ppm	4.090; 109%	3.615; 96%
Profile 1, Config 1	Top Wall	3.589 ppm	4.603; 128%	2.640; 74%
FTWC STACK DATA_SF6_Testing.xlsx; worksheet Aug23_InfraRan_Calcs				

On 10/02/2019, a secondary tracer gas mixing measurement was made for Profile 2 (large blower) and flow Configuration 3 (rigid pipe and 50' flex tubing). This test was performed with centerline injection, using the "T" shaped injector that will be used in the actual FTWC vent process. This test met the COV criterion for mixing, but the maximum concentration deviation failed. This appeared to be an artifact of the SF6 tracer "tuning" process in which the gas injection is adjusted until an acceptable level of gas is achieved in the duct. In this test, the gas injection was too high initially and saturated the detector. We reduced the gas injection flow and waited until it appeared the detectors stabilized, then immediately began traverse measurements at A1. Looking at the data, it appears that the detectors had not fully flushed out the high levels of gas experienced during saturation; the A1 point concentration for each instrument was higher than any other point on the traverse by a significant margin. If A1 is disregarded, the maximum deviation criteria is met for the test. Since the cause of the high data point is clear, we are using the "disregard A1" evaluation as the official reporting value for this test. Data from the Profile 2 tracer gas testing appears in Table 7.

Table 7: Tracer Gas Mixing Test Details Profile 2; Config 3; Center Line Injection					
Avg SF6 Conc., Center 2/3 Duct	Std Dev SF6 Conc, Center 2/3 Duct	COV	Full Plane Avg ppm	Max Conc, ppm; %	Min Conc., ppm; %
1.423 ppm	0.239 ppm	16.8%	1.44 ppm	2.03; 141%	1.12; 78%
disregarding point A1 (see notes)			1.40 ppm avg	1.75 ppm max; 125% of mean	
FTWC STACK DATA_SF6_Testing.xlsx; worksheet Profile2_BigBlower					

To further evaluate the deviation above, we performed two other checks. The first looked at the A and B traverses independently of each other; this is a common practice in testing when there may be variation in the injection media. When independent evaluations are done for each traverse, all checks are easily met. The traverses are well within COV criteria and maximum deviation from mean criteria. A third test uses average concentration values overall in comparison to the average concentration of each traverse to develop a correction factor that can be used to account for tracer media injection variability. When this correction factor is applied, all ANSI N13.1 criteria are again met. The COV and maximum deviation criteria are easily met for this third analysis.

It should be noted that the instruments did not log the data during the Profile 2 test on 10/02/2019, so multi-point averages are not available. Test data analysis here are simply based on the hand-written records of concentrations. Future testing should ensure that the detector logging functions are properly enabled prior to each test. Also, testing should ensure that detectors are briefly flushed with ambient air prior to beginning traverse measurements to avoid issues encountered during this Profile 2 test.

Aerosol Particles Mixing: (N/A)

Criteria:
1. Coefficient of variation over the central 2/3 area of the cross section within 20%

Results:

Since there is no particulate pollutant of concern with the FTWC testing, no aerosol mix testing was performed.

Scanned images of paperwork from all tests appear on subsequent pages.

Report by: Analytical & measurement support by:
Rebecca Lattin & David Fuehne   Sam Sherrill and Richard Sturgeon
Rad Air Emissions Management Team   RAEM Team
EPC-Compliance Programs   EPC-Compliance Programs
October 7, 2019

Evaluation of document
"Lattin and Fuehne 2019 Evaluation of FTWC Vent System LA-UR-19-30127"

Murray E. Moore, PhD, PE
Radiation Protection Services
Aerosol Engineering Facility
Los Alamos National Laboratory

March 19, 2020

Introduction

A document (Lattin and Fuehne 2019) presents Los Alamos test results between a tested exhaust flow system (Profile 1) and a candidate exhaust flow system (Profile 2). This document (Moore 2020) verifies that the Lattin and Fuehne approach (2019) correctly validated the candidate flow system according to national standard guidelines (ANSI/HPS 1999).

Table 1. Summary of the criteria that compare the tested and candidate flow systems.

The LAUR-19-30127 document summarizes results in tabular format	Summary of the (ANSI/HPS 1999) criteria to compare the tested and candidate flow systems	Did this review (Moore 2020) indicate that the analysis in LAUR-19-30127 is correct?
Table 3 part 1	Systems must be geometrically Similar	Yes
Table 3 Part 2.1	Flow Scaling Factor	Yes
Table 3 Part 2.2	Hydraulic Diameter	Yes
Table 3 Part 2.3	The Reynolds numbers for the tested and candidate flow systems must be greater than 10,000 (the Reynolds number is dimensionless).	Yes. The LAUR-19-30127 document has an error of 6% to 8% in their Reynolds number calculation (due to differences in air density calculations). This review (Moore 2020) calculated the tested and candidate Reynolds numbers to be between 98,357 and 242,477. Therefore, the Reynolds numbers exceed the (Re=10,000) criterion, even while accounting for the 6% to 8% error. This review (Moore 2020) recommends computing the air density from local pressure measurements or tabulated values e.g. NOAA 1976 with corrections for ambient temperature. This would account for the measured (monthly) variation of average air density in Los Alamos between 0.924 kg/m3 and 0.991 kg/m3 (Bowen 1990).
Table 3 Part 3	Candidate stack velocity profile COV less than 20% over inner 2/3 of the duct center area.	Yes
Table 3 Part 4	Difference between velocity COVs of tested and candidate systems is not more than 5%.	Yes
Table 3 Part 5	Sampling location of the candidate and sampling duct must be similar and in the center 1/3 area of duct.	Yes

References

ANSI/HPS 1999. Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities. ANSI/HPS N13.1-1999. Health Physics Society. McLean, VA.

Bowen BM 1990. Los Alamos Climatology. Los Alamos National Laboratory publication LA-11735-MS.

Lattin and Fuehne 2019. Evaluation of FTWC Vent System. Los Alamos National Laboratory Unrestricted Release publication LA-UR-19-30127.

NOAA 1976. The US Standard Atmosphere. National Oceanic and Atmospheric Administration. ST 76-1562.

Appendices

(1) Moore 2020 Red-lined hard copy with notes of "Lattin and Fuehne 2019. Evaluation of FTWC Vent System. LAUR-19-30127."

(2) PDF rendition of Excel spreadsheet: "Moore 2020 Verification of calcs from -LAUR-19-30127 Evaluation of FTWC Vent System-.xlsx"

LA-UR-19-30127
Approved for public release; distribution is unlimited.

Title: Evaluation of FTWC Vent System

Author(s): Lattin, Rebecca Renee
Fuehne, David Patrick

Intended for: Report
Environmental Regulatory Document

Issued: 2019-10-07

Evaluation of FTWC Vent System

[handwritten: ME Moore, PhD, PE / Murray & Moore / Z-117546 / 3-12-2020]

[handwritten: all unlabeled (undated) red-line comments were written on 3-12-2020. All other red-line comments have the date of writing.]

Abstract

A monitored exhaust system has been designed for use in venting the Flanged Tritium Waste Containers (FTWCs) at LANL. This system will provide controlled exhaust and emissions monitoring for the FTWCs, and also provide general area exhaust around the venting operations to measure any emissions which may bypass the primary vent system. A full description of the process and need for the system is described in the Pre-Construction Application[1] for this project. This document describes the commissioning testing performed on the FTWC vent system to prepare it for use. The system has been tested and shown to meet ANSI standard requirements and is fully suitable for use.

A. Background

Airborne emissions of radioactive material from Department of Energy facilities are regulated by the Clean Air Act, in the Radionuclide NESHAP[2] or Rad-NESHAP. Methods for measuring emissions are *[handwritten: there are five tests, but this is correctly explained in Table 2.]* described in the Rad-NESHAP and also in the American National Standards Institute (ANSI) standard[3] N13.1, which has been incorporated by reference into the Rad-NESHAP. Under ANSI N13.1, four tests are performed to determine if the proposed sampling location is adequate for representative sampling of the emissions exhaust stream. These include: (1) a measurement of the velocity profile, (2) a measurement of the cyclonic flow angle, (3) a measurement of mixing of tracer gas, and (4) a measurement of mixing of large aerosol particles. The tests will show the stack either meets all the needed specifications or that it is not in compliance. Note that since the FTWC emissions only contain airborne tritium in gas or vapor form, the fourth test regarding aerosol particulate mixing is not needed.

[handwritten: FIGURE 1]

The exhaust system was built by EPC-CP personnel using modular "Quick Flange" duct work, 10 inches in diameter. The system has a blower to supply air movement, a rigid section of duct approximately 12 feet long, and one or two flexible duct sections of up to 25 feet each. Another five foot section of rigid duct is connected to the blower's vertical exhaust to discharge air above the worker breathing zone. Measurements on the original system indicated that the first system, using a small ¾ horsepower blower, did not provide sufficient flow to safely vent the FTWCs during initial venting operations at TA-54. A larger blower (2 horsepower) was purchased that would fit the existing duct work and provide sufficient flow. Figure 1 shows a line schematic of the exhaust system. *[handwritten: Side note: the blower fan curve & system curve could have estimated the correct blower.]*

The full suite of ANSI N13.1 testing was performed on the original system (dubbed "Profile 1"). Under ANSI N13.1 parameters, testing from one system can be applied to a second system if certain parameters are met; this is the "scale model criteria" described later in this document. If these criteria

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[1] LA-UR-18-26283 r2, "Application for Pre-Construction Approval under 40 CFR Subparts A and H for Venting of Flanged Tritium Waste Containers (FTWCs) at TA-54." May 16, 2019. This application was transmitted to EPA Region 6 via memo EPC-CP-19-137, "Transmittal of Application for Pre-Construction Approval and Notice of Intent to Start Operations under 40 CFR 61 Subparts A and H for Venting of Flanged Tritium Waste Containers (FTWCs) at TA-54," May 17, 2019.

[2] National Emissions Standards for Hazardous Air Pollutants – Radionuclides. Title 40, Code of Federal Regulations, Part 61, Subpart H, "National Emissions Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities." Referred to as the Rad-NESHAP. Compliance with this regulation at LANL is managed by the Environmental Protection and Compliance Division – Compliance Programs Group, EPC-CP.

[3] ANSI/HPS N13.1-1999, "Sampling and Monitoring Releases of Airborne Radioactive Substances From the Stacks and Ducts of Nuclear Facilities." Issued 1999, reaffirmed without changes in 2011.

document and in the attached data sheets. Note that for tests below, the coefficient of variation (COV) is defined as the standard deviation of the measurements divided by the average of the measurements.

Table 2: Test Result Summary of ANSI N13.1 Sampling Location Requirements for FTWC Venting, Profile 1			
Test	**Criteria**	**Pass/ Fail**	**Test Data**
Uniform Velocity Distribution	Coefficient of variation over the central 2/3 area of the cross section must be less than 20%	Pass	Config 1: 3.45% Config 2: 3.91% Config 3: 2.40%
Absence of Cyclonic Flow	Flow angle <20° [*average*] relative to the long axis of the stack and nozzle inlet	Pass	Config 1: 4.1° Config 2: 8.3° (Prof.2) Config 3: 5.8°
Tracer Gas Well Mixed *this is OK (ME MOORE)*	Tracer gas concentration over the central 2/3 area of the cross section has a coefficient of variation within 20%. *(less than)* Five injection points tested.	Pass	North Inject: 4.1% South Inject: 10.9% Center Inject: 3.1% Bottom Inject: 2.9% Top Inject: 13.6%
max value of local Tracer Gas ~~Well Mixed~~	The maximum value of tracer gas concentration shall not be more than 130% of the mean value at any point on a complete Method 1 set of velocity traverse points; minimum value > 70% mean.	Pass	*max min* North: 106%; 92% South: 118%; 83% Center: 109%; 94% Bottom: 109%; 96% Top: 128%; 74%
Aerosol Well Mixed	Aerosol gas over the central 2/3 area of the cross section has a coefficient of variation within 20%	Pass	N/A Aerosol test not needed if particulate pollution not present

[handwritten right margin: Section 5.3 ANSI N13.1-1999 says to inject tracer gas at five locations. yes, OK.]

[handwritten right margin: good!]

These test results show that Profile 1 meets ANSI N13.1 criteria for sample siting. Under this ANSI standard, these data can be used as a scale model for similar systems. In this case, Profile 1 is used as a scale model for Profile 2 operations. Section C shows the criteria that must be met for scale model applicability.

C. Scale Model Applicability

In order for a tested system to be used as a scale model for new systems (dubbed the "candidate system"), certain criteria must be met under ANSI N13.1. These criteria are described in Table 3, along with the applicability to the FTWC ventilation systems (Profile 1 and Profile 2). Note the criteria numbers are from ANSI N13.1; criterion 2 in the standard has three separate components that are split out in Table 3.

ANSI/HPS N13.1-1999

[Handwritten annotations at top: "This page is not part of LA-UR-19-30127. Compare to (p. 4 of 8) "p. 6 of 34" in LA-UR-19-30127."]

add additional traverse points or to adjust the points in Method 1 for velocity, tracer gas, or aerosol mapping at the boundary demarcating 2/3 of the cross sectional area of the stack or duct. Also, points may need to be adjusted because of limitations of Method 1 on the proximity of a sampling point to a wall.

If only gaseous contaminants can be present, an additional criterion beyond that for aerosol particles must be met. Anomalously high concentrations of gases or particulate matter could occur near the wall in a stack flow if contaminant is injected into the near-wall region of the flow boundary layer. Accordingly, an additional mixing criterion is that at no point in a complete grid for velocity setup in accordance with 40 CFR 60, Appendix A, Method 1, shall the concentration of tracer gas be any higher than 30% above the mean concentration value in that sampling plane. Because of possible limitations due to the physical size of a particle sampling nozzle, the measurement of the concentration of 10 μm AD aerosol particles may be difficult and subject to errors in the vicinity of the wall of a stack or duct. Consequently, the 30% criterion is not applicable for aerosol particles. A summary of the acceptance criteria for a sampling location is given in table 4.

The above criteria for uniformity are selected to reflect the reality of experimental errors expected in sampling from stacks in the field. The 10±1 μm AD test aerosol particle diameter was selected because of the need for a test aerosol whose aerodynamic behavior clearly exhibits inertial effects that could adversely influence mixing; because it has been previously used in the performance specification of sample nozzles and transport lines (Rodgers 1987; McFarland et al. 1989); because it is relatively easily generated in either monodisperse (single particle size) or polydisperse forms and released into stack flow; and because it can be present in stacks and ducts of the nuclear industry (Rodgers 1995). In some cases, it may be necessary to use a larger particle size as a basis for the criterion (see all of clause 4.3 and subclause 5.1.5).

Often nuclear facilities have multiple stacks or ducts that are of similar design. For such situations, it is not necessary to completely test the sampling location in a candidate stack or duct for compliance with the requirements given in clause 5.2.2 provided that:

[Handwritten: Compare to Table 3 LA-UR 19-30127]

1)   A geometrically similar stack or duct (one with proportional critical dimensions) has been tested and the sampling location has been found to comply with the requirements of clause 5.2.2. Critical dimensions are those associated with components of the effluent flow system that can influence the degree of contaminant mixing and/or the velocity profile. The prior testing may be conducted either on a tack or duct in the field, or it may be conducted on a scale model.

2)   The product of mean velocity (see eqn A-2) times hydraulic diameter of the candidate stack or duct is within a factor of six of that of the tested stack or duct, and the hydraulic diameter of the stack or duct is at least 250 mm at the sampling location. The Reynolds numbers based on hydraulic diameter of both the candidate stack or duct and the tested stack or duct are greater than 10,000 (see eqns B-1 and B-2 for examples of expressions that can be used for calculation of Reynolds numbers).

[Handwritten annotations: "Table 3, Part 2.1", "Part 2.2", "2.3", "Table 3 Part 3"]

3)   The velocity profile in the candidate stack or duct meets the requirements of clause 5.2.2.2.

4)   The difference between velocity COVs of the two systems is not more than 5%.

[Handwritten: Table 3 Part 4]

5)   The sampling location in the candidate stack or duct is placed at a geometrically similar location to that in the tested stack.

[Handwritten: Table 3 Part 5.]

If these requirements are fulfilled, the sampling location in the second stack or duct is acceptable.

If the requirements of clause 5.2.2 are met, sampling may be conducted at a single point. The nozzle shall be placed within the center one-third of the cross sectional area of the stack or duct at the qualified location.

D. FTWC Vent System Testing Details

More detailed descriptions of the criteria from ANSI N13.1 and results of testing appear here. Calculation sheets will follow in the published version. Calculation worksheet files are called out after each summary table. Raw field measurement forms are maintained in the EPC-CP records system.

Uniform Velocity Distribution: (PASS, all configurations)

Criteria:
1. Coefficient of variation over the central 2/3 area of the cross section must be less than 20%

Results:
The sampling location stack velocities were measured using a pitot tube and an electronic digital manometer on 8/14/2019 for Profile 1. Profile 2 data was measured 9/27/2019.

Good.
God

Note from ANSI N13.1 Sec. 6.2.2.1 to avoid thermal anemometeR, due to vapor Condensation and debris fouling possibility.

Table 4: Velocity Profile Test Details				
Profile & Configuration	Description	Avg Velocity (fpm), Center 2/3 Duct	Velocity Std. Dev., Center 2/3 Duct	COV
Profile 1, Config 1	Small blower; Rigid duct only	3395	117	3.45%
Profile 1, Config 2	Small blower; Rigid duct + 25' Flex	2164	85	3.91%
Profile 1, Config 3	Small blower; Rigid duct + 50' Flex	1458	35	2.40%
Profile 2, Config 2	Large blower; Rigid duct + 25' Flex	3575	244	6.81%
Profile 2, Config 3	Large blower; Rigid duct + 50' Flex	2850	136	4.78%
Calculation workbook: worksheets:	FTWC STACK DATA_VelocityProfile.xlsx sheet: Config 1 – Rigid Duct Only sheet: Config 2 – 25ft Flex sheet: Config 3 – 50ft Flex sheet: Profile 2			

All COV values less than 20%.

Absence of Cyclonic Flow: (PASS)
Criteria:
1. Flow angle <20° relative to the long axis of the stack and nozzle inlet

Results:
Cyclonic measurements were taken on 8/19/2019 for Profile 1, Configurations 1 and 3. We determined that if these met flow angle criteria, Configuration 2 would also meet the criteria. On 10/2/2019, Configuration 2 was measured using Profile 2 (large blower) for completeness. The above requirement was met for all configurations, as shown in Table 5.

Evaluation of FTWC Vent System

→ Good - compare to Table 2, Row 3. Moore 3-18-2020

Table 6a: Tracer Gas Mixing Test Details – Coefficient of Variation, Center 2/3 Duct Area				
Profile & Configuration	Injection Point	Avg SF6 Conc.	Std Dev SF6 Conc	COV
Profile 1, Config 2	North Wall	3.499 ppm	0.145 ppm	4.1%
Profile 1, Config 1	South Wall	3.225 ppm	0.351 ppm	10.9%
Profile 1, Config 1	Center Line	3.262 ppm	0.102 ppm	3.1%
Profile 1, Config 1	Bottom Wall	3.737 ppm	0.110 ppm	2.9%
Profile 1, Config 1	Top Wall	3.578 ppm	0.488 ppm	13.6%
FTWC STACK DATA_SF6_Testing.xlsx; worksheet Aug23_InfraRan_Calcs				

Table 6b: Tracer Gas Mixing Test Details – Maximum Deviation, Full Plane Area				
Profile & Configuration	Injection Point	Mean SF6 conc., ppm	Max ppm; %	Min ppm; %
Profile 1, Config 2	North Wall	3.500 ppm	3.715; 106%	3.215; 92%
Profile 1, Config 1	South Wall	3.195 ppm	3.775; 118%	2.653; 83%
Profile 1, Config 1	Center Line	3.306 ppm	3.595; 109%	3.113; 94%
Profile 1, Config 1	Bottom Wall	3.763 ppm	4.090; 109%	3.615; 96%
Profile 1, Config 1	Top Wall	3.589 ppm	4.603; 128%	2.640; 74%
FTWC STACK DATA_SF6_Testing.xlsx; worksheet Aug23_InfraRan Calcs				

→ None more than 130%.

On 10/02/2019, a secondary tracer gas mixing measurement was made for Profile 2 (large blower) and flow Configuration 3 (rigid pipe and 50' flex tubing). This test was performed with centerline injection, using the "T" shaped injector that will be used in the actual FTWC vent process. This test met the COV criterion for mixing, but the maximum concentration deviation failed. This appeared to be an artifact of the SF6 tracer "tuning" process in which the gas injection is adjusted until an acceptable level of gas is achieved in the duct. In this test, the gas injection was too high initially and saturated the detector. We reduced the gas injection flow and waited until it appeared the detectors stabilized, then immediately began traverse measurements at A1. Looking at the data, it appears that the detectors had not fully flushed out the high levels of gas experienced during saturation; the A1 point concentration for each instrument was higher than any other point on the traverse by a significant margin. If A1 is disregarded, the maximum deviation criteria is met for the test. Since the cause of the high data point is clear, we are using the "disregard A1" evaluation as the official reporting value for this test. Data from the Profile 2 tracer gas testing appears in Table 7.

→ Disregarding sampling point A1 is reasonable, since the explanation has a physical experimental basis. Also, point A1 is not inside the central 2/3 area, see page 15/34.

FTWC VELOCITY PROFILE

Compare to Table 4.
3-18-2020   Config 1 - Rigid Duct Only

350034FT	Profile 1	Flow Config #01

Rigid duct only

~~35 FTWC 00 Profile 1~~ *We changed the designation to 350034FT, profile 1, config 01*

8/14/2019

start time	2:15
end time	2:30
avg temp	77.6 F
RH	45.14
Static Pressure	-1.143
Backpurge location	A5
Reading	0.621
Pref (HG")	23.15152
Elv (prof, ft)	7217 google earth est
Elv (ref, ft)	7424 TA-6
Cp	0.99 std tube
T (K)	537.6
Pbar	23.35852
Pg	-0.084217
Ps	23.274303
MW	29
K	4577.8215
Velocity	3322.2498 ft/min
Stack Area	0.5454 ft^2
Flow Rate	1811.955 cfm

Traverse A	1	2	average
A1	0.472	0.455	0.4635
A2	0.505	0.514	0.5095
A3	0.548	0.553	0.5505
A4	0.542	0.561	0.5515
A5	0.639	0.658	0.6485
A6	0.617	0.606	0.6115
A7	0.534	0.524	0.529
A8	0.451	0.445	0.448
A Centerline	0.600		

Traverse B	1	2	average
B1	0.484	0.536	0.51
B2	0.535	0.576	0.5555
B3	0.575	0.562	0.5685
B4	0.547	0.584	0.5655
B5	0.592	0.583	0.5875
B6	0.554	0.538	0.546
B7	0.515	0.523	0.519
B8	0.46	0.45	0.455
B Centerline	0.561		

Center 2/3 COV calcs, based on:		
	sqrt(dP)	velocity ft/min
Average =	0.7492	3395
Std Dev =	0.0258	117
COV =	3.45%	3.45%

sqrt A	Center2/3 dP	Velocity
0.68081		
0.71379	0.71379	3235
0.74196	0.74196	3363
0.74263	0.74263	3366
0.80529	0.80529	3650
0.78198	0.78198	3544
0.72732	0.72732	3296
0.66933		

sqrt B	Center2/3 dP	Velocity
0.71414		
0.74532	0.74532	3378
0.75399	0.75399	3417
0.75200	0.75200	3408
0.76649	0.76649	3474
0.73892	0.73892	3349
0.72042	0.72042	3265
0.67454		

average sqrt 0.73306
across full plane of stack

Data Entry & Calculations by: **Sam Sherrill, EPC-CP, 8/23/2019**

Verification & Validation by: **David Fuehne, EPC-CP, 10/3/2019**

FTWC VELOCITY PROFILE

Config 3 - 50ft Flex

Compare to Table 4.   3-18-2020

350034FT Profile 1   **Flow Config #03**

35 FTWC 00 Profile 2 *We changed the designation to 350034FT,   profile 1, config 03*

Rigid duct with 2 flex ducts

date	8/14/2019
start time	2:45
end time	3:00
avg temp	75.9 F
RH	48.1
Static Pres	-1.15
Backpurge B4	
Reading	0.109
Pref (HG")	23.15152
Elv (prof, f)	7217 google earth est
Elv (ref, ft)	7424 TA-6
Cp	0.99 std tube
T (K)	535.9
Pbar	23.35852
Pg	-0.084733
Ps	23.273787
MW	29
K	4570.6284
Velocity	1439.7857 ft/min
Stack Area	0.5454 ft^2
Flow Rate	785.25914 cfm

Traverse A	1	2	average
A1	0.094	0.096	0.095
A2	0.101	0.099	0.1
A3	0.103	0.104	0.1035
A4	0.101	0.104	0.1025
A5	0.106	0.11	0.108
A6	0.11	0.108	0.109
A7	0.105	0.103	0.104
A8	0.097	0.093	0.095
A Centerline	0.103		

Traverse B	1	2	average
B1	0.104	0.102	0.103
B2	0.102	0.107	0.1045
B3	0.111	0.114	0.1125
B4	0.109	0.107	0.108
B5	0.101	0.101	0.101
B6	0.098	0.102	0.1
B7	0.097	0.091	0.094
B8	0.081	0.083	0.082
B Centerline	0.109		

sqrt A	Center2/3 dP	Velocity
0.30822		
0.31623	0.31623	1431
0.32171	0.32171	1456
0.32016	0.32016	1449
0.32863	0.32863	1487
0.33015	0.33015	1494
0.32249	0.32249	1459
0.30822		

sqrt B	Center2/3 dP	Velocity
0.32094		
0.32326	0.32326	1463
0.33541	0.33541	1518
0.32863	0.32863	1487
0.31780	0.31780	1438
0.31623	0.31623	1431
0.30659	0.30659	1387
0.28636		

0.31819   average sqrt ne of stack

Center 2/3 COV calcs, based on:	sqrt(dP)	velocity ft/min
Average =	0.3223	1458
Std Dev =	0.0077	35
COV =	2.40%	2.40%

Data Entry & Calculations by: Sam Sherrill, EPC-CP, 8/23/2019

Verification & Validation by: David Fuehne, EPC-CP, 10/3/2019

FTWC VELOCITY PROFILE

Profile 2

Compare to Table 4   3-18-2022

Test date: 9/27/2019

Summary data from "Individual velocity" printouts from STACKS database.

Profile 2, Configuration 2

	Avg	3575
	StdDev	244
	COV	6.81%

	FullPlane	Ctr2/3
A1	2974	
A2	3101	3101
A3	3401	3401
A4	3560	3560
A5	3850	3850
A6	3921	3921
A7	3859	3859
A8	3816	
B1	3469	
B2	3564	3564
B3	3654	3654
B4	3602	3602
B5	3669	3669
B6	3426	3426
B7	3287	3287
B8	3019	

Profile 2, Configuration 3

	Avg	2850
	StdDev	136
	COV	4.78%

	FullPlane	Ctr2/3
A1	2527	
A2	2618	2618
A3	2783	2783
A4	2896	2896
A5	2991	2991
A6	3032	3032
A7	3016	3016
A8	2966	
B1	2598	
B2	2661	2661
B3	2854	2854
B4	2876	2876
B5	2929	2929
B6	2841	2841
B7	2707	2707
B8	2535	

Data Entry & Calculations by: *David Fuehne, EPC-CP, 10/3/2019*

Verification & Validation by: *Rebecca Lattin, EPC-CP, 10/7/2019*

Config 2

CYCLONIC FLOW ANGLE MEASUREMENT

350034FT   Profile 2   Flow Config #02   "Big Blower"

Rigid duct with 2 flex ducts

10/2/2019

Average Rotation Angle:	8.31
	degrees

start time   12:25
end time   12:04

	Velocity Pressure	Angle at VP=0	abs value of Alpha
A1	-0.132	-17	17
A2	-0.088	-12	12
A3	-0.025	-6	6
A4	0.022	2	2
A5	0.191	15	15
A6	0.337	15	15
A7	0.285	12	12
A8	0.288	15	15
B1	-0.04	-4	4
B2	-0.117	-9	9
B3	0.013	4	4
B4	-0.014	-3	3
B5	-0.121	-7	7
B6	-0.029	-2	2
B7	-0.058	-8	8
B8	-0.038	-2	2

manometer verification test

	EDM	Reference	%diff
test1	0.151	0.15	-0.7%
test2	0.286	0.29	1.4%
test3	0.573	0.58	1.2%

Data Entry & Calculations by: David Fuehne, EPC-CP, 10/3/2019

Verification & Validation by: Rebecca Lattin, EPC-CP, 10/7/2019

SF6 Tracer Gas Testing   Aug23_InfraRan_Calcs

	A	B	C	D	E	F	G	H	I
1	Measurements were taken by Sam Sherrill, Rebecca Lattin, and Dave Fuehne on 8/23/2019.								
2									
3	The right probe was connected to instrument 91 while the left probe was connected to instrument 92.								
4									
5	25 ft of flex duct was connected to the rigid section of the stack. 25 ft of flex duct was also connected to								
6	the top of the stack to vent the SF6 out of the room.								
7									
8			Wilkes InfraRan detectors; designated instrument 91 and 92 (last 2 digits of prop #)						
9			Performance checked on Oct 5, 2018 - ok ✔				ME MOORE 3-18-2020		
10				Adjusted R-square of trend line shows fit >95%.					
11									
12			Used both instruments together - dual-headed probe.						
13			Inst 91 did not immediately restart after lunch; successfully restarted						
14				before end of A-traverse (see BottomDuct injection)					
15									
16			When we measured an outlier data point, we repeated that traverse point						
17				measurement and averaged the 2 measurement values together for analysis.					
18				This happened only during "top injection" series, points A4, B1, and B3.					
19				Note that B1 is outside Center 2/3 and not included in COV calcs.					
20									
21			First test - is COV <20% for central 2/3 of duct area? Discard A1, A8, B1, B8 pts.						
22				Results show COV is less than 20% for all individual injection points					
23				and also for full analysis of data combined over all injection points.					
24									
25			Second test - maximum deviation from mean. Is max value across the full						
26				sample plane (all traverse points) less than 130% of mean?					
27				Results of all combined injection points show 132% for all points					
28				combined; but individual injection points are all <130%					
29				Also verified that minimum values are >70% of mean.					
30									
31	*Data Analysis by Rebecca Lattin, 9/12/2019; Validation & Verification by Dave Fuehne, 10/3/2019*								
32									
33	Full Plane Data								
34	InjectPt	Traverse	Inst91	Inst92	Copied from RawData_Inst91+92_All_Aug23				
35	Botm_Inj	A1	#DIV/0!		4.09 Columns AG - AJ				
36	Botm_Inj	A2	#DIV/0!	4.0025					
37	Botm_Inj	A3	#DIV/0!	3.855					
38	Botm_Inj	A4	#DIV/0!	3.7225					
39	Botm_Inj	A5	#DIV/0!	3.7125					
40	Botm_Inj	A6	#DIV/0!	3.71					
41	Botm_Inj	A7	#DIV/0!	3.795					
42	Botm_Inj	A8	3.4025	3.72					
43	Botm_Inj	Ambient	-0.18	0.0125					
44	Botm_Inj	B1	3.4825	3.7275					
45	Botm_Inj	B2	3.45	3.7					
46	Botm_Inj	B3	3.4125	3.6375					
47	Botm_Inj	B4	3.375	3.615					
48	Botm_Inj	B5	3.3925	3.6175					
49	Botm_Inj	B6	3.4875	3.705					
50	Botm_Inj	B7	3.555	3.7725					
51	Botm_Inj	B8	3.5925	3.8225					
52	Botm_Inj	CL	#DIV/0!	0					
53	Botm_Inj	CL	#DIV/0!	0.195					
54	Botm_Inj	CL	#DIV/0!	4.03					
55	Botm_Inj	CL	3.3925	3.6725					
56	Botm_Inj	CL	3.39	3.66					
57	Botm_Inj	CL	3.365	3.6125					

	P	Q	R	S	T	U	V
1							
2	**Max Value Test: Using Full Traverse Plane**			Not called out in ANSI std;			
3	Maximum value measured must be less than 130%			Look at Min val vs Avg;			
4	of the average value for that injection pt			Min Value greater than 70% of mean?			
5		Inst91	Inst92				
6	All_Inj_pts avg	3.309	3.475	Avg	3.309	3.475	
7	Max value	4.3575	4.6025	Min	2.465	2.640	
8	% mean	132%	132%	%Avg	74%	76%	
9		break down by injection pt.					
10	NorthInj_avg	3.339	3.500	Avg	3.339	3.500	
11	Max	3.545	3.715	Min	3.078	3.215	
12	% mean	106%	106%	%Avg	92%	92%	
13							
14	ClInj_avg	3.214	3.306	Avg	3.214	3.306	
15	Max	3.500	3.595	Min	3.03	3.1125	
16	% mean	109%	109%	%Avg	94%	94%	
17							
18	SouthInj_avg	3.125	3.195	Avg	3.125	3.195	
19	Max	3.658	3.775	Min	2.685	2.653	
20	% mean	117%	118%	%Avg	86%	83%	
21							
22	BottomInj_avg	3.461	3.763	Avg	3.461	3.763	
23	Max	3.593	4.090	Min	3.375	3.615	
24	% mean	104%	109%	%Avg	98%	96%	
25							
26	TopInj_Avg	3.446	3.589	Avg	3.446	3.589	
27	Max	4.358	4.603	Min	2.465	2.640	
28	% mean	126%	128%	%Avg	72%	74%	
29							
30							
31							
32	Transfering data for analysis points of interest.						
33	Use all traverse points on sample plane for max value test						
34	InjectPt_TravPt	Inst91	Inst92				
35	Botm_Inj_A1	#DIV/0!	4.09	*Detector91*			
36	Botm_Inj_A2	#DIV/0!	4.0025	*did not*			
37	Botm_Inj_A3	#DIV/0!	3.855	*immediately*			
38	Botm_Inj_A4	#DIV/0!	3.7225	*restart*			
39	Botm_Inj_A5	#DIV/0!	3.7125	*after*			
40	Botm_Inj_A6	#DIV/0!	3.71	*lunch break*			
41	Botm_Inj_A7	#DIV/0!	3.795	*Fixed by 11:30*			
42	Botm_Inj_A8	3.4025	3.72				
43	Botm_Inj_Ambient						
44	Botm_Inj_B1	3.4825	3.7275				
45	Botm_Inj_B2	3.45	3.7				
46	Botm_Inj_B3	3.4125	3.6375				
47	Botm_Inj_B4	3.375	3.615				
48	Botm_Inj_B5	3.3925	3.6175				
49	Botm_Inj_B6	3.4875	3.705				
50	Botm_Inj_B7	3.555	3.7725				
51	Botm_Inj_B8	3.5925	3.8225				
52	Botm_Inj_CL						
53	Botm_Inj_CL						
54	Botm_Inj_CL						
55	Botm_Inj_CL						
56	Botm_Inj_CL						
57	Botm_Inj_CL						

SF6 Tracer Gas Testing   Aug23_InfraRan_Calcs

	J	K	L	M	N	O
34		Inject Location	Point	Inst91	Inst92	
58		Botm_Inj	CL			
59		Botm_Inj	CL			
60		Ctr_Inj	A1			
61		Ctr_Inj	A2	3.175	3.25	
62		Ctr_Inj	A3	3.235	3.3075	
63		Ctr_Inj	A4	3.0475	3.14	
64		Ctr_Inj	A5	3.115	3.205	
65		Ctr_Inj	A6	3.095	3.2075	
66		Ctr_Inj	A7	3.175	3.28	
67		Ctr_Inj	A8			
68		Ctr_Inj	Ambient			
69		Ctr_Inj	Ambient			
70		Ctr_Inj	B1			
71		Ctr_Inj	B2	3.41	3.5025	
72		Ctr_Inj	B3	3.2675	3.365	
73		Ctr_Inj	B4	3.1525	3.2425	
74		Ctr_Inj	B5	3.03	3.1125	
75		Ctr_Inj	B6	3.14	3.2475	
76		Ctr_Inj	B7	3.175	3.28	
77		Ctr_Inj	B8			
78		Ctr_Inj	CL			
79		Ctr_Inj	CL			
80		Ctr_Inj	CL			
81		Ctr_Inj	CL			
82		Ctr_Inj	CL			
83		North_Inj	A1			
84		North_Inj	A2	3.28	3.465	
85		North_Inj	A3	3.3375	3.5175	
86		North_Inj	A4	3.32	3.52	
87		North_Inj	A5	3.3325	3.5325	
88		North_Inj	A6	3.3775	3.5825	
89		North_Inj	A7	3.43	3.65	
90		North_Inj	A8			
91		North_Inj	Ambient			
92		North_Inj	B1			
93		North_Inj	B2	3.095	3.2325	
94		North_Inj	B3	3.1425	3.28	
95		North_Inj	B4	3.1925	3.3375	
96		North_Inj	B5	3.525	3.6475	
97		North_Inj	B6	3.455	3.5625	
98		North_Inj	B7	3.545	3.66	
99		North_Inj	B8			
100		North_Inj	CL			
101		North_Inj	CL			
102		North_Inj	CL			
103		North_Inj	CL			
104		North_Inj	CL			
105		North_Inj	CL			
106		North_Inj	CL			
107		North_Inj	CL			
108		North_Inj	CL			
109		North_Inj	CL			
110		North_Inj	CL			
111		North_Inj	CL			
112		North_Inj	CL			
113		North_Inj	CL			

SF6 Tracer Gas Testing   Aug23_InfraRan_Calcs

	A	B	C	D	E	F	G	H	I
34	InjectPt	Traverse	Inst91	Inst92	Copied from RawData_Inst91+92_All_Aug23				
114	North_Inj	CL	3.33	3.48					
115	North_Inj	CL	3.355	3.51					
116	South_Inj	A1	3.0975	3.165					
117	South_Inj	A2	2.9425	3.05					
118	South_Inj	A3	3.315	3.395					
119	South_Inj	A4	3.3975	3.43					
120	South_Inj	A5	3.0975	3.0575					
121	South_Inj	A6	3.085	3.1275					
122	South_Inj	A7	2.685	2.6525					
123	South_Inj	A8	2.69	2.72					
124	South_Inj	Ambient	-0.06	-0.02					
125	South_Inj	Ambient	-0.1	-0.06					
126	South_Inj	Ambient	-0.12	-0.07					
127	South_Inj	Ambient	-0.1025	-0.055					
128	South_Inj	B1	3.495	3.565					
129	South_Inj	B2	3.57	3.66					
130	South_Inj	B3	3.6575	3.775					
131	South_Inj	B4	3.54	3.655					
132	South_Inj	B5	2.915	3.035					
133	South_Inj	B6	2.805	2.915					
134	South_Inj	B7	2.835	2.9425					
135	South_Inj	B8	2.8725	2.9825					
136	South_Inj	CL	3.25	3.295					
137	South_Inj	CL	3.1975	3.2					
138	South_Inj	CL	3.2725	3.4025					
139	South_Inj	CL	3.275	3.3925					
140	Top_Inj	A1	3.4975	3.6925					
141	Top_Inj	A2	3.525	3.745					
142	Top_Inj	A3	3.0375	3.2825					
143	Top_Inj	A4	2.465	2.75					
144	Top_Inj	A4	3.1875	3.3975					
145	Top_Inj	A5	3.62	3.8825					
146	Top_Inj	A6	4.04	4.1925					
147	Top_Inj	A7	4.1725	4.3975					
148	Top_Inj	A8	3.8375	4.1					
149	Top_Inj	Ambient	-0.16	0.025					
150	Top_Inj	Ambient	0.3575	0.455					
151	Top_Inj	B1	2.9925	3.065					
152	Top_Inj	B1	2.5625	2.64					
153	Top_Inj	B2	3.6675	3.49					
154	Top_Inj	B3	3.2475	3.065					
155	Top_Inj	B3	3.1375	3.04					
156	Top_Inj	B4	3.32	3.405					
157	Top_Inj	B5	3.19	3.3875					
158	Top_Inj	B6	3.63	3.815					
159	Top_Inj	B7	3.985	4.2425					
160	Top_Inj	B8	4.3575	4.6025					
161	Top_Inj	CL	2.63	2.9525					
162	Top_Inj	CL	3.0125	3.225					
163	Top_Inj	CL	2.8875	3.1425					
164	Top_Inj	CL	3.42	3.5925					
165	Top_Inj	CL	3.83	3.95					
166	Top_Inj	CL	3.6125	3.7575					
167	Top_Inj	CL	3.9075	3.9825					

SF6 Tracer Gas Testing   Aug23_InfraRan_Calcs

	P	Q	R	S	T	U	V
34	InjectPt_TravPt	Inst91	Inst92				
114	North_Inj_CL						
115	North_Inj_CL						
116	South_Inj_A1	3.0975	3.165				
117	South_Inj_A2	2.9425	3.05				
118	South_Inj_A3	3.315	3.395				
119	South_Inj_A4	3.3975	3.43				
120	South_Inj_A5	3.0975	3.0575				
121	South_Inj_A6	3.085	3.1275				
122	South_Inj_A7	2.685	2.6525				
123	South_Inj_A8	2.69	2.72				
124	South_Inj_Ambient						
125	South_Inj_Ambient						
126	South_Inj_Ambient						
127	South_Inj_Ambient						
128	South_Inj_B1	3.495	3.565				
129	South_Inj_B2	3.57	3.66				
130	South_Inj_B3	3.6575	3.775				
131	South_Inj_B4	3.54	3.655				
132	South_Inj_B5	2.915	3.035				
133	South_Inj_B6	2.805	2.915				
134	South_Inj_B7	2.835	2.9425				
135	South_Inj_B8	2.8725	2.9825				
136	South_Inj_CL						
137	South_Inj_CL						
138	South_Inj_CL						
139	South_Inj_CL						
140	Top_Inj_A1	3.4975	3.6925				
141	Top_Inj_A2	3.525	3.745				
142	Top_Inj_A3	3.0375	3.2825				
143	Top_Inj_A4	2.465	2.75				
144	Top_Inj_A4	3.1875	3.3975				
145	Top_Inj_A5	3.62	3.8825				
146	Top_Inj_A6	4.04	4.1925				
147	Top_Inj_A7	4.1725	4.3975				
148	Top_Inj_A8	3.8375	4.1				
149	Top_Inj_Ambient						
150	Top_Inj_Ambient						
151	Top_Inj_B1	2.9925	3.065				
152	Top_Inj_B1	2.5625	2.64				
153	Top_Inj_B2	3.6675	3.49				
154	Top_Inj_B3	3.2475	3.065				
155	Top_Inj_B3	3.1375	3.04				
156	Top_Inj_B4	3.32	3.405				
157	Top_Inj_B5	3.19	3.3875				
158	Top_Inj_B6	3.63	3.815				
159	Top_Inj_B7	3.985	4.2425				
160	Top_Inj_B8	4.3575	4.6025				
161	Top_Inj_CL						
162	Top_Inj_CL						
163	Top_Inj_CL						
164	Top_Inj_CL						
165	Top_Inj_CL						
166	Top_Inj_CL						
167	Top_Inj_CL						

Profile2_BigBlower

	B	C	D	E	F	G	H
30							
31	2nd review;	Each traverse evaluated independently; look at max value deviation					
32							
33	Maximum Deviation:	A-Avg		2.31	1.69		
34		A-Max		2.65	2.03		
35		A-%Diff		115%	120%	Pass, Max <130%	✓
36							
37		B-Avg		1.74	1.20		
38		B-Max		1.83	1.27		
39		B-%Diff		105%	106%	Pass, Max <130%	✓
40							
41	Check COVs with independent traverse evaluations						
42		A-Center2/3 Avg:		2.27	1.65		
43		A-Center2/3 StdDev:		0.08	0.06		
44		A-COV		3.6%	3.8%	Pass COV < 20%	✓
45							
46		B-Center2/3 Avg:		1.74	1.20		
47		B-Center2/3 StdDev:		0.05	0.05		
48		B-COV		2.9%	4.3%	Pass COV < 20%	✓

Handwritten in red: Good. M E Moore 3-18-2020

3rd Review - correct data readings for possible variability in tracer gas injection.
correction factor: (Full Plan avg)/(Traverse Avg)
Data from each traverse is corrected with traverse-specific factor; then COV and max calcs done as in part 1

Correction Factors to correct for injection variability:

Correct for tracer injection variation;

	Inst91	Inst92
Center 2/3 Avg	2.01	1.43
Center 2/3 StdDev	0.06	0.06
COV	3.2%	4.1%
Full Plane Avg	2.02	1.44
Maximum	2.32	1.74
%diff	115%	120%

Both OK!

Traverse A	
Inst91	0.870
Inst92	0.844

Traverse B	
Inst91	1.156
Inst92	1.187

Both OK!

Profile2_BigBlower

Past evaluation of SF6 detector instruments shows that for most changes, the detector will settle down at a new level about 30 seconds after changing the SF6 concentration (e.g., raw logger data from Aug 23 testing).

For Oct 02 test, we adjusted SF6 flow until we obtained level in the 1-4 ppm range that appeared to be stable; then immediately began measuring A1 concentration. As values continued to drop at A1 (note 2-min interval), we realized that data may not have been fully stable after all. Raw data was not logged by the instrument on Oct 2 test due to user error.

Max Deviation analysis:

a) The initial full-profile analysis showed the maximum measured point was more than 130% of the mean. More analysis is required to determine if there really is a problem.

b) Data show that the initial readings at point A1 were both higher than others; it appears that the detectors had not fully "flushed" after adjusting the SF6 injection rate.

c) Removing A1 from the analysis shows deviations of less than 130% of the mean, meeting compliance requirements.

d) We will use these values without A1 for our analysis report, as it represents most reasonable assessment without further data adjustment. Reported value = 125% of mean, using detector 92.

e) Further analysis: first, looking at 2 traverses independently. All criteria are met when looking at traverse A and traverse B independently. See data calcs above.

f) Second, we used typical correction methods to adjust for potential variations in flow rate. Correction factor: (Full Plane Avg) / (Traverse Avg); diff factor for each traverse. After multiplying original data by these factors, all compliance requirements are met.

Initial assessment with reasons for excluding A1, paired with subsequent traverse-specific testing and corrected data testing, lead me to conclude that the as-operated system meets EPA criteria for tracer gas mix testing.

- D. Fuehne, 10/3/2019

Reynolds Number

Calculating Reynolds Number for air flow in stacks or ducts
and applicability for scale model data collection.

To calculate Reynold's number *Source: ANSI/HPS N13.1-1999 p. 60 eqn B-1; many others as well*

$$R_e = \frac{\rho * U * D}{\mu}$$

Re = Reynolds Number (dimensionless)
ρ = air density, kg/m3
U = linear velocity (m/sec) in duct
D = effective diameter (m) of duct
μ = air viscosity, N*s/m2, or kg/(s*m)

An approximation for Los Alamos County (from Victor Martinez) is:
Re = 7.49 * U * D   U in ft/min, D in inches

Note- in past spreadsheets, I quoted above eqn but calcs used constant with value=7.349. not sure which value of constant is actually correct.
When I calc the approximation, I get a constant value = 7.404   DPF 8/3/2012 (using elevation data below)
Calculations to determine Reynolds number, using both of the above methods, appear below.

Constants used in calculation:
Density & viscosity of air at elevation. (Hndbk Chem/Phys, 73rd ed, 1992-1993, p14-13)

	elevation (m)	density (kg/m3)	viscosity (N*s/m2) or [kg/(m*s)]	
	2000	1.0066	1.73E-05	
	2500	0.95695	1.71E-05	*see summary by*
(TA-53 met twr)	2200	0.987	1.72E-05 (linear interpolations)	*MEMoore*

ta6 (ft, m)	
	7424
	2263
ta35-FTWC	
	7217
	2200

3-18-2020

Requirement under ANSI/HPS N13.1-1999 for scale model applicability - all R_e must be greater than 10,000

REYNOLDS NUMBER CALCULATIONS $R_e > 1E+04$: OK or not OK

Config 2 - Rigid Duct + 1 section of flex duct (25 ft)

Candidate Stack
350034FT, Profile 2, config2   **10** inches   0.254 meters,   10 inches
Air velocity: the system design flow rate is   0.90 m3/sec   **1,915** actual cfm *Measured 9/27/2019*
The cross-sectional area is   0.05 m2   0.55 sq feet
the linear velocity is   17.84 m/sec   3511 ft/min

Calculating Reynold's Number:	using formula above:	2.60E+05	OK	USING same duct
	using Los Alamos approximation:	2.63E+05	OK	with small (2HP) blower as Scale Model

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Scale Model Stack
350034FT, Profile 1, config2   **10** inches   0.254 meters,   10 inches

Air velocity: the system design flow rate is   0.54 m3/sec   **1,154** actual cfm *Measured 8/14/2019*
The cross-sectional area is   0.05 m2   0.55 sq feet
the linear velocity is   10.75 m/sec   2116 ft/min

Calculating Reynold's Number:	using formula above:	1.57E+05	OK
	using Los Alamos approximation:	1.58E+05	OK

Table 3 part 1   "Geometrically Similar"

Parameter	Magnitude	Units	Formula	Description	Location
Dduct1	0.833	ft	=10/12	Duct diameter in profile 1, feet	Fig. 1
Dduct2	0.833	ft	=10/12	Duct diameter in profile 2, feet	Fig. 1

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Table 3 Part 2.1	Flow Scaling Factor

Parameter	Magnitude	Units	Formula	Description	Location
Uvel22	3511	FPM		Profile 2, Config 2 velocity	Table 1
Uvel12	2115	FPM		Profile 1, Config 2 velocity	Table 1
VelDiaRatio12	1.66		=Uvel22*Dduct2/(Uvel12*Dduct1)	Ratio between profile 2 and 1 of the products of the velocities and duct diameters (for Config 2).	Table 3 (2.1)
Uvel23	2802	FPM		Profile 2, Config 3 velocity	Table 1
Uvel13	1440	FPM		Profile 1, Config 3 velocity	Table 1
VelDiaRatio12	1.95		=Uvel23*Dduct2/(Uvel13*Dduct1)	Ratio between profile 2 and 1 of the products of the velocities and duct diameters (for Config 3).	Table 3 (2.1)

Table 3 Part 2.2	Hydraulic Diameter

Parameter	Magnitude	Units	Formula	Description	Location
Dmm1	254	mm	=Dduct1* mmpf	Duct diameter in profile 1, mm	Table 3 (2.2)
Dmm2	254	mm	=Dduct1* mmpf	Duct diameter in profile 2, mm	Table 3 (2.2)

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Table 3 Part 2.3	Reynolds number

Location	Parameter	Magnitude	Units	Formula	Description
	Profile 1, config 2				
	Dmm1p	0.254	m	=Dduct1*mmpf/1000	Duct diameter in profile 2, m
Table 1	QACFM12	1154	ACFM		Flow rate profile 2 config 2 (ACFM)
	Qm3s12	0.5446	m3/s	=QACFM12*m3s_ACFM	Flow rate profile 2 config 2 (ACFM)
NOAA 1976	rho12p	0.9864	kg/m3		Air density - profile 2 config 2
NOAA 1976	visc12	1.715E-05	kg/m sec		Air viscosity - profile 2 config 2
	Re12	157024		=4*rho12p*Qm3s12/(PI()*visc12*Dmm1p)	Reynolds number - profile 2 config 2

Table 3 (2.3)

Location	Parameter	Magnitude	Units	Formula	Description
	Profile 2, config 2				
	Dmm2p	0.254	m	=Dduct2*mmpf/1000	Duct diameter in profile 2, m
Table 1	QACFM22	1915	ACFM		Flow rate profile 2 config 2 (ACFM)
	Qm3s22	0.9038	m3/s	=QACFM22*m3s_ACFM	Flow rate profile 2 config 2 (ACFM)
NOAA 1976	rho22p	0.9864	kg/m3		Air density - profile 2 config 2
NOAA 1976	visc22	1.715E-05	kg/m sec		Air viscosity - profile 2 config 2
	Re22	260572.038		=4*rho22p*Qm3s22/(PI()*visc22*Dmm2p)	Reynolds number - profile 2 config 2

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Table 3 Part 2.3	Reynolds Number (continued)						Comparison between LAUR-19-30127 and Moore 2020		
profile, config	Temp avg, F	Duct Dia, m	Q, ACFM	Q, m3/s	dens kg/m3 (Moore)	viscosity, kg m sec (Moore)	Reynolds (Moore 2020)	Reynolds LAUR-19-30127	%Error Rey nolds
2, 2	70.3	0.254	**1915**	0.9038	0.9179	1.715E-05	242477	260000	-6.74
1, 2	76	0.254	**1154**	0.5446	0.9082	1.715E-05	144575	157000	-7.91
2, 3	70.3	0.254	**1528**	0.7211	0.9179	1.715E-05	193475	207000	-6.53
1, 3	75.9	0.254	**785**	0.3705	0.9083	1.715E-05	98357	107000	-8.08

Screen capture from noted Excel sheet.

This calculation has not been validated, and is only referenced for this review.

NOAA USA 1976 The US Standard Atmosphere ST 76-1562			
Elevation (ft)=	7217.8	Elevft	
Elevation (m) =	**2200.0**	Elevm	$=Elevft*mpf$
Molecular scale temperature Eq 23 (K) =	**273.9**	Tm	$=Tmb+Lmb*Elevm$
Pressure at elevation Eq 33b (Pa) =	**77541.0**	Pair	$=P0*(Tmb/Tm)^{\wedge}(g0*M0/(R0*Lmb))$
Density at elevation Eq 42 (kg/m3) =	**0.98641**	rhoNOAA	$=Pair*M0/(R0*Tm)$
Viscosity of air Eq 51 (kg/m*s) =	**1.720E-05**	viscair	$=(B*Tm^{\wedge}1.5)/(Tm+S)$

Calc - from NOAA 1976 The US Standard Atmosphere ST 76-1562.xlsx

NOAA tables based on the Tm molecular scale temperature (K).
Ambient values use NOAA pressure and ambient temperature.

Air ambient temperature (F) =	75.90	degF	
Air ambient temperature (K) =	**297.39**	degK	$=((degF-32)*(5/9)) + 273$
Density at ambient elevation and temp (kg/m3) =	*0.9083*	rhoair	$=Pair*M0/(R0*degK)$

Compare NOAA P/P0 (2500 m) = 0.73715.	0.765271		$=Pair/P0$
Compare NOAA ρ/ρ0 (2500 m) = 0.78119.	0.805231		$=rhoNOAA/rho0$
	0.741496		$=rhoair/rho0$

| Table 3 Part 3 | Candidate stack velocity profile COV less than 20% over inner 2/3 of the duct center area. |

LAUR-19-30127 data. pg. 15/34

Profile 2, Configuration 2

Avg	3575			Avg	3574.5
StdDev	244			StdDev	243.5
COV	6.81%			COV	6.81%

	FullPlane	Ctr2/3
A1	2974	
A2	3101	3101
A3	3401	3401
A4	3560	3560
A5	3850	3850
A6	3921	3921
A7	3859	3859
A8	3816	
B1	3469	
B2	3564	3564
B3	3654	3654
B4	3602	3602
B5	3669	3669
B6	3426	3426
B7	3287	3287
B8	3019	

Profile 2, Configuration 3

Avg	2850			Avg	2850.3
StdDev	136			StdDev	136.2
COV	4.78%			COV	4.78%

	FullPlane	Ctr2/3
A1	2527	
A2	2618	2618
A3	2783	2783
A4	2896	2896
A5	2991	2991
A6	3032	3032
A7	3016	3016
A8	2966	
B1	2598	
B2	2661	2661
B3	2854	2854
B4	2876	2876
B5	2929	2929
B6	2841	2841
B7	2707	2707
B8	2535	

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Table 3 Part 4	Difference between velocity COVs of tested and candidate systems is not more than 5%.

	COV velocity		COV velocity	**Difference**
Profile 1 Config 2	**3.91%**	Profile 2 Config 2	**6.81%**	**2.90%**
Profile 1 Config 3	**2.40%**	Profile 2 Config 3	**4.78%**	**2.38%**

| Table 3
Part 5 | Sampling location of the candidate and sampling duct must be similar and in the center 1/3 area of duct. |

The geometry of Profile 1 (the tested duct) and Profile 2 (the candidate duct) are identical, except for the use of a 3/4 HP blower in Profile 1 and a 2 HP blower in Profile 2.

Appendix: Notes, constants and references

Temp11	77.6		Profile 1 config 1 350034FT
Temp12	76		Profile 1 config 2 350034FT
Temp13	75.9		Profile 1 config 3 350034FT

Conversion	Value	Definition	
mmpf	304.8	millimeters per feet	
m3s-ACFM	4.719E-04	cubic meters per second t	Walker et al 1984

FPM		Feet per minute

Walker FW, Miller DG, Feiner F. 1984. Chart of the nuclides, with physical constants, conversion factors and periodic table: General Electric.